APPENDIX A

SAMPLE DESIGN PROBLEM

A-1. Problem. Design a natural-draft incinerator for burning an average of 2,000 pounds of mixed refuse per hour consisting of 35 percent nonedible garbage containing 50 percent water, and 65 percent rubbish containing 10 percent water and 15 percent solid inerts; atmospheric temperature, 60 degrees F. (519 degrees F. absolute); combustion chamber temperature, 1,600 degrees F. (2,059 degrees F. absolute); average stack temperature, 1,500 degrees F. (1,959 degrees F. absolute). The chemical analysis of 1 pound of the refuse on a moisture free and solid inerts free basis is assumed to be as follows: Carbon, 0.47 pound; hydrogen, 0.07 pound; nitrogen, 0.04 pound; oxygen, 0.42 pound.

A-2. Preliminary design. A type I incinerator should be used to provide the required service. Using the preliminary design factors in table 2-1 and the capacity requirements set out in paragraph 2-3, the preliminary design is as follows:

Design capacity	2,000 x 1.25	2,500 pounds per hour
Effective grate area	2,500 x 0.022	55.0 square feet
C. I. grate area (assumed)		36 square feet
Hearth area (firebrick)	$\frac{(55.0 - 36)}{0.6}$	31.7 square feet
Inside width of furnace (assumed)		6 feet
Height of furnace arch above C.I. grate		6 feet
Horizontal cross-sectional area of mixing chamber	55.0 x 0.25	13.75 square feet
Horizontal cross-sectional area of combustion chamber	55.0 x 0.6	33.0 square feet
Stack cross-sectional area	55.0 x 0.22	12.10 square feet
Flue cross-sectional area	55.0 x 0.25	13.75 square feet

To provide the above areas, the dimensions will be:

Length of C.I. grate	6 feet 0 inches
Length of hearth	5 feet 6 inches
Length of mixing chamber	2 feet 3 inches
Length of combustion chamber	5 feet 8 inches
Width of flue	3 feet 6 inches
Height of flue to crown of arch	4 feet 0 inches
Size of stack	3 feet 6 inches square

The above dimensions are the dimensions shown in figure A-1.

A-3. Check of design. To assure conformance with the basic requirements of paragraph 2-3, a check involving heat release, heat balance, quantities of gases, velocities, draft, etc., should now be made of the preliminary design. The areas, volume, and dimensions shown on Standard Plan No. 414:43-369 and figure A-1 are used in this check. The specific heats, heats of vaporization, and molecular weights of the various substances are taken from standard handbooks. The heat absorbed by various gases as the temperature rises over a specified range can be ascertained by use of figure A-2. The following illustrates the method of checking the design. The oxygen requirements for complete combustion of 1 pound of moisture-free and solid inerts-free material of the stated chemical analysis are:

For burning carbon to CO_2 -------	0.47 x 32 / 12 -----	1.25 pounds
For burning hydrogen to H_2O -----	0.07 x 16 / 2 -----	.56 pound
		1.81 pounds
Less oxygen in refuse ----------------------------------		.42 pounds
Oxygen to be supplied by air --------------------------		1.39 pounds

The air required to furnish the above amount of oxygen is 1.39 divided by 0.23 or 6.04 pounds (oxygen in air is 23 percent by weight). The nitrogen in this quantity of air amounts to 6.04 x 0.76 or 4.59 pounds. Therefore, the products of combustion of 1 pound of moisture-free solid inerts-free refuse will be:

H_2O -----------------------	0.07 x 18 / 2 ---------	0.63 pound
CO_2 -----------------------	0.47 x 44 / 12 --------	1.72 pounds
N_2 ------------------------	0.04 + 4.59 -----------	4.63 pounds
Total weight of gases ----------------------		6.98 pounds

For conditions of burning all rubbish without wet garbage, the severest conditions under which the furnace will be required to operate insofar as heat release is involved, the products of combustion of 1 pound refuse, taking into consideration the content of 10 percent water and 15 percent solid inerts (0.75 pound on a moisture-free, solid inerts-free basis), will be:

H_2O ---------------	0.10 / 0.63 x 0.75 -----------	0.57 pound
CO_2 ---------------	1.72 x 0.75 ------------------	1.29 pounds
N_2 ---------------	4.63 x 0.75 ------------------	3.47 pounds
Total weight of gases as product of combustion ----		5.33 pounds

The heat of combustion of 1 pound of moisture-free and solid inerts-free refuse (using Dulong's formula for the determination of

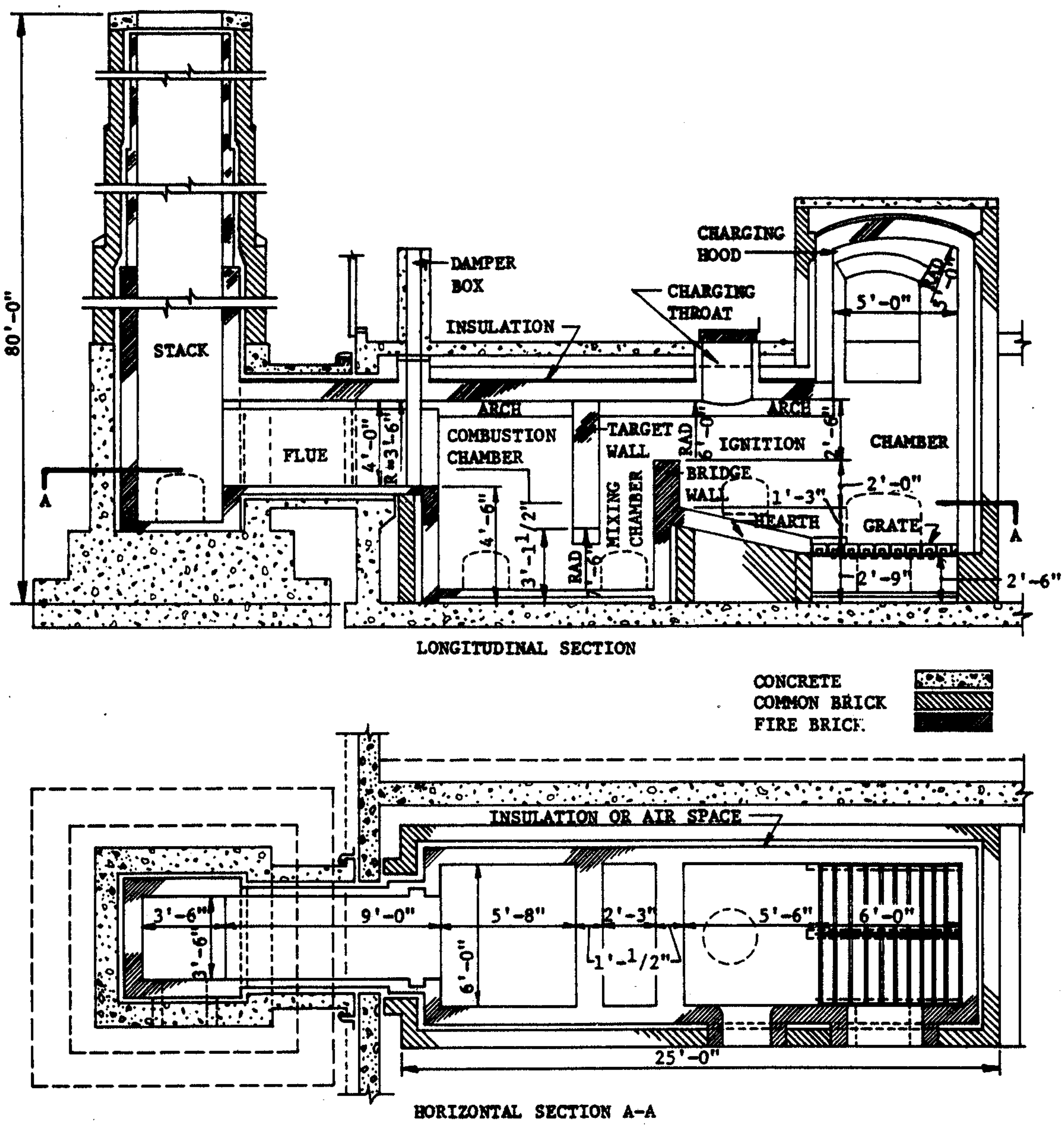

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FIGURE A-1. INCINERATOR FURNACE AND STACK

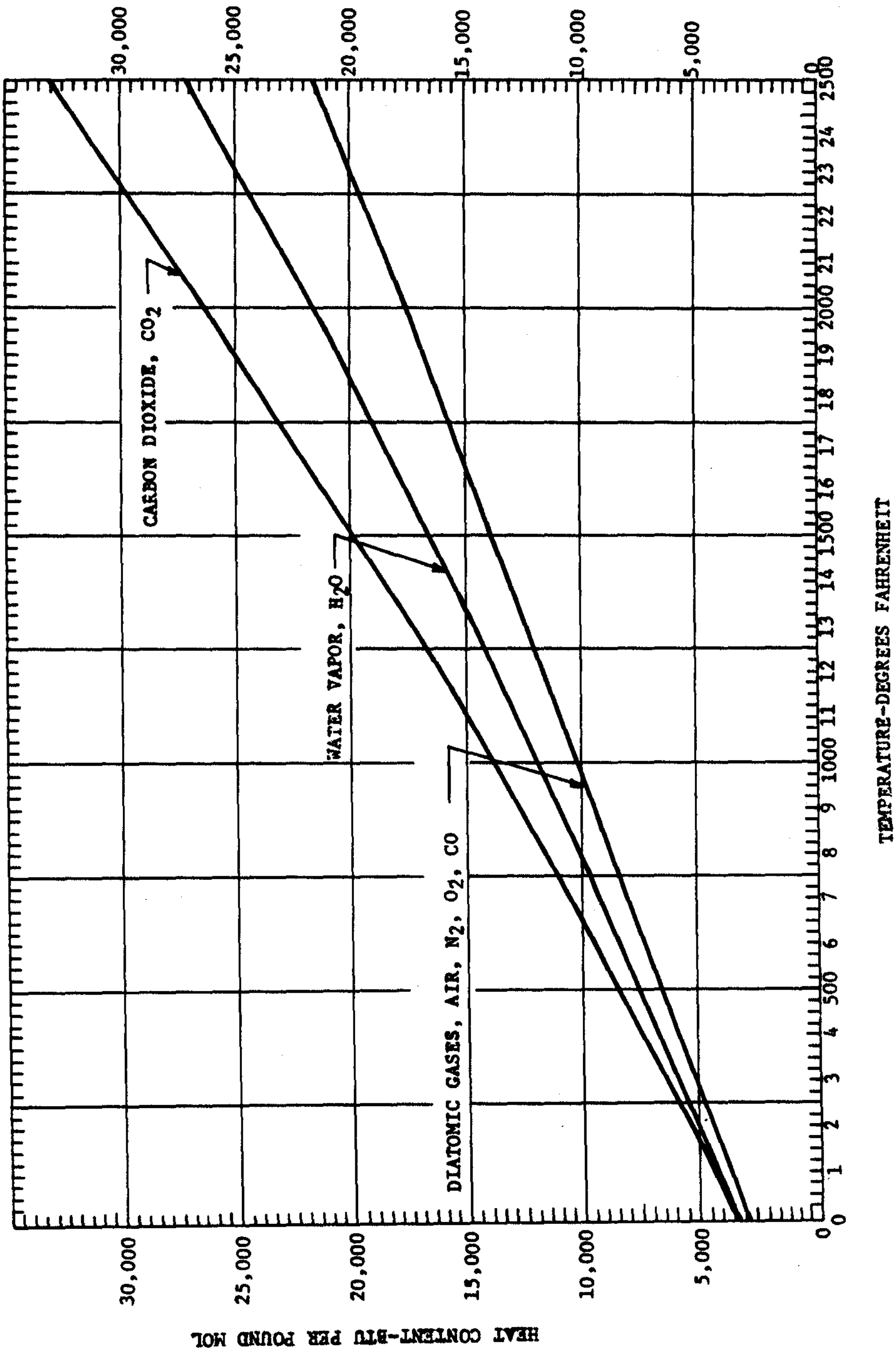

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FIGURE A-2. CHART OF HEAT CONTENT OF GASES (CONSTANT PRESSURE) calorific values) will be 14,500 x 0.47 + 62,000 [0.07 - (0.42/8)] equal to 7,900 Btu. The heat of combustion of 1 pound of the refuse, taking moisture and inert solids into consideration, will be 7,900 x 0.75 or 5,925 Btu. A portion of this heat combustion will be lost through radiation and solid inerts, a portion will be absorbed in heating and evaporating water, and a portion (the larger portion) will be absorbed in heating the gases. In figure A-2, which may be used in the determination of the heat absorbed by various gases, the difference between Btu per mol (defined as m pounds where m denotes molecular weight) at two temperatures in question is the heat absorbed by the gas as its temperature rises from the lower to the higher value. Btu per mol divided by the molecular weight (not atomic weight) gives Btu per pound. It should be noted that, for instance, the chart is graduated in degrees F. zero on the scale being 32 below the freezing temperature of water and not absolute zero which is used in most heat formulas. The heat lost or absorbed will be as indicated in the following heat balance:

Evaporating water from 60 degrees F.	--- 0.57 x 1122	--- 640 Btu
Heating water vapor from 212 degrees F. to 1,600 degrees F. (weight multiplied by the difference in heat content per mol at the two temperatures divided by molecular weight)	--- 0.57 x 12,300 / 18	--- 390 Btu
Heating CO_2 from 60 degrees F. to 1,600 degrees F.	--- 1.29 x 17,100 / 44	--- 502 Btu
Heating N_2 from 60 degrees F. to 1,600 degrees F.	--- 3.47 x 11,200 / 28	--- 1,388 Btu
Radiation through furnace walls, assuming a loss of 1,000 Btu per square feet per hour and a total radiating surface of 350 square feet	--- 350 x 1,000 / 2,500	--- 140 Btu
Heating 300 gallons of water per hour from 60 degrees F. to 180 degrees F. for can wash	--- 300 x 8.33 x 120 / 2,500	--- 120 Btu
Loss through solid inerts (assuming a specific heat of 0.20 and a temperature of 600 degrees F.)	--- 0.15 x 0.20 x (600-60)	--- 16 Btu

Subtotal --- 3,196 Btu
Balance to be absorbed by excess air (5,925 - 3,196) --- 2,729 Btu

Total heat of combustion (as above) ---------------- 5,925 Btu

The excess air that will be required to absorb 2,729 Btu so that the combustion chamber temperature will not exceed 1,600 degrees F. (see fig A-2 for heat absorbed between 60 degrees F. and 1,600 degrees F.) will be 2,729 x 28.9 / 11,200, which is equal to 7.04 pounds. Therefore, the total weight of gases per pound of refuse burned (the products of combustion plus the excess air used for controlling maximum temperature of the combustion chamber) will be 5.33 + 7.04 which is equal to 12.37 pounds. As this gas has a molecular weight which is practically the same as air, it will be considered air from this point on. The volume of 1 pound of air at 60 degrees F. (519 degrees F. absolute) and 14.7 psi barometric pressure is approximately 13.1 cubic feet. Using the foregoing computations, formulas, quantities, temperatures, etc., the following determinations are made:

Total weight of gas produced per second	12.37 x 2,500 / 3,600	8.59 pounds
Total volume of gas passing through the combustion chamber	8.59 x 13.1 x 2,059 degrees /519 degrees	446 cfs
Velocity through combustion chamber	446 / (5.67 feet x 6 feet)	13.1 fps
Velocity through flue	446 / (3.5 feet x 4 feet)	31.8 fps
Velocity through mixing chamber	446 / (2.25 feet x 6 feet)	33.0 fps
Average volume of gas passing through the stack	8.59 x 13.1 x 1,959 degrees / 519 degrees	425 cfs
Velocity through stack	425 / (3.5 feet x 3.5 feet)	34.7 fps
Heat release per hour per cubic foot of furnace volume	5,925 x 2,500 / 930	15,925 Btu
Combustion time (total furnace volume excluding charging hood divided by volume of gas produced per second)	720 / 446	1.61 seconds
Combustion chamber volume per pound of gas produced per second	5 feet 8 inches x 6 feet x 7 feet 11 inches / 8.59	31.4 cubic feet
Draft loss in stack and flue (L = 51.5 feet + 9 feet = 60.5 feet)	$1.1 \times 10^{-6} \times 1{,}959 \times 8.59 \times 60.5 \times 14 / 12.25^3$	0.073 inch
Velocity head	$0.119 \times 34.7^2 \times 14.7 / (14.7 \times 1{,}959)$	0.073 inch

Loss through five turns through openings which have an average area of 14 square feet and an average perimeter of 16 feet taken as a stack whose height is 5 x 12 $\sqrt{14}$ or 224 feet --------- $1.1 \times 10^{-6} \times 2{,}059 \times 8.59^2 \times 224 \times 16 / 14^3$ -------------- 0.218 inch

Loss through grate (assumed) ------------------------- 0.250 inch

Total draft requirements --------- 0.073 + 0.073 + 0.218 + 0.250 ---------------------- 0.614 inch

Required stack height --------- $\dfrac{0.614}{0.52 \times 14.7\ (1/519 - 1/1{,}959)}$ 56.7 feet

which is 1 foot less than the height above grate shown in figure A-1.

From the above analysis the design complies with paragraph 2-4.